UNIVERSITI PUTRA MALAYSIA

OPTIMIZATION OF MATERIAL REMOVAL RATE AND SURFACE ROUGHNESS USING THE TAGUCHI METHOD

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By

POORIA MATOORIAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfillment of the Requirement for the Degree of Master of Science

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DEDICATION

May this work commemorate my parents, who dedicated themselves to bringing me up. Through all life's sunny and rainy days, I feel you were there, which encouraged me to head up with smile. I would like to thank you in my heart, and I know you are listening.

To all my friends I thank you for the past 26 years. I cannot think of better people to be with through this dance we call life.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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January 2008

Chairman : Shamsudin Sulaiman, PhD

Faculty : Engineering

A non-conventional hybrid machining method called electrical discharge turning (EDT) process is optimized in this research. The EDT process is a suitable method to produce small components with cylindrical geometries. This process is a type of hybrid electrical discharge machining (EDM), hence the material is removed by the action of electrical discharges between the tool electrode and the workpiece. It means materials of any hardness can be removed as long as the workpiece can conduct electricity. This makes the EDT process suitable for machining hard, difficult-to-machine materials. In this process linear geometry of a tool electrode reproducing the same geometry in the rotating workpiece cylindrically. In this study, a dressed copper block (8mm × 10mm × 50mm) serving as the forming tool electrode is fixed on the work table and rotary workpiece uses the rotational motion of 4th (C) axis of the machine. The Taguchi Robust Design method was used to determine the optimum machining performance namely the highest material removal rate (MRR) and the lowest surface roughness (SR) for EDT of High Speed Steel (HSS) 5%-Cobalt. Six control factors namely, Intensity, Pulse-on time, Pulse-off time, Voltage,

Servo, and Spindle speed were considered. Based on the analysis of variance (ANOVA) all six factors were influential for MRR but for SR rotational speed did not show any influence. Intensity was the most significant factor for both response of MRR and SR. Signal to Noise (S/N) analysis was performed and optimum levels of the mentioned factors for highest MRR and the lowest SR was achieved based on the S/N ratios. Results of confirmation tests shown the improvement of MRR and SR in optimum condition were 9.17 and 6.54 dB respectively. Finally general linear regression models were derived for 95% confidence interval to predict the output response. The p-value for the used α-level of 0.05 concluded that at least one of the regression coefficients is significantly different from zero and the linear predictors are not sufficient to explain the variation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGOPTIMUM KADAR PENYINGKIRAN BAHAN DAN KEKASARAN PERMUKAAN MENGGUNAKAN KAEDAH TAGUCHI

Oleh

POORIA MATOORIAN

Januari 2008

Pengerusi : Shamsuddin Sulaiman, PhD

Fakulti : Kejuruteraan

Proses memesin hibrid bukan convensional dipanggil mesin larik nyahcas elektrik (EDT) dioptimumkan dalam penyelidikan ini. Proses EDT adalah kaedah sesuai untuk menghasilkan komponen kecil bergeometri selinder. Oleh kerana proces ini adalah hibrid dari pemesinsn nyahcas elektik (EDM), suatu bahan akan dikeluarkan melalui tindakan nyahcas elektrik antara elektrod dan bahankerja. Ini bermakna bahan dari setiap kekerasan boleh dibuang selama bahan boleh mendapat bekalan elektrik. Ini menjadikan proses EDT sangat sesuai untuk pemesinan yang sukar atau bahan yang sukar untuk dimesin. Dalam proses ini geometri lelurus alat elektrod dihasilkan semula dengan geometri yang sama dalam bahan kerja berpusing tetapi berbentuk selinder. Dalam kajian ini, satu blok kuprum (8mm x 10mm x 50mm) bertugas sebagai alatan elektrod di pasang pada meja kerja dan bahan kerja berpusing menggunakan gerakan pusingan paksi ke 4 (C). Kaedah Taguchi Robust Design adalah digunakan sebagai satu pendekatan bagi mengenal pasti pengoptimum prestasi mesin untuk kadar pembuangan bahan (MRR) dan kekasaran permukaan (SR) terendah untuk EDT keluli halaju tinggi (HSS) 5%. Enam kawalan faktor iaitu,

Intensity, Pulse-on time, Pulse-off time, Voltage, Servo, dan *Spindle speed*; diambil kira bagi tujuan penyelidikan ini. Daripada analisis varian (ANOVA) kesemua enam faktor telah dikenalpasti mempengaruhi MRR tetapi untuk SR kelajuan pusingan tidak menunjukkan pengaruhnya. *Intensity* telah kelihatan sebagai faktor yang paling ketara dalam MRR dan SR. Analisis petanda kebisingan (S/N) telah dilaksanakan dan paras optimum faktor berkenaan untuk MRR tertinggi dan SR terendah telah dicapai berdasarkan nisbah S/N. Ujian pengesahan menunjukkan pembaikan MRR dan SR paras optimum adalah 9.17 dB dan 6.54 dB. Akhirnya model regresi am dihasilkan untuk 95% jurang keyakinan untuk menjangkan tindakbalas output. Disimpulkan bahawa nilai-p untuk paras-α 0.05 memberi perbezaan pekali regresi yang ketara daripada sifar dan jangkaan lelurus tidak mencukupi untuk menerangkan perbezaanya.

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- Engineer Aminollah Mohammadi, Isfahan University of Technology.
- Engineer Davood Karimi, University of Tarbiat Modarres.

I certify that an Examination Committee has met on 14 January 2008 to conduct the final examination of Pooria Matoorian on his Master of Science entitled "Optimization of Material Removal Rate and Surface Roughness Using The Taguchi Method" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the relevant degree. Members of the Examination Committee were as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date: 10 April 2008

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LIST OF ABBREVIATIONS / GLOSSARY OF TERMS

ANOVA	Analysis of Variance
AWG	Abrasive Water Jet
CBN	Cubic Boron Nitride
CNC	Computer Numerical Control
DOE	Design of Experiment
DOF	Degree of Freedom
EDG	Electrical Discharge Grinding
EDM	Electrical Discharge Machining
EDT	Electrical Discharge Turning
EWR	Electrode Wear Ratio
FFEs	Fractional Factorial Experiments
GA	Genetic Algorithm
HAZ	Heat Affected Zone
HB	Higher is Better
HF	High Frequency
HMP	Hybrid Machining Process
HRC	Hardness Rockwell C
HSS	High Speed Steel
LB	Lower is Better
MMC	Metal Matrix Composite
MRM	Material Removal Mechanism
MRR	Material Removal Rate
NB	Nominal is Best

OA	Orthogonal Array
QC	Quality Control
RC	Resistor Capacitor circuit
RF	Radio Frequency
S/N	Signal to Noise ratio
SF	Surface Finish
SQ	Surface Quality
SR	Surface Roughness
SS	Sum of Squares
TWP	Tool Wear Process
TWR	Tool Wear Ratio
WEDG	Wire Electrical Discharge Grinding
WEDM	Wire Electrical Discharge Machining
WEDT	Wire Electrical Discharge Turning

CHAPTER 1

INTRODUCTION

1.1 Background of Electrical Discharge Machining (EDM)

1.1.1 Nontraditional Machining

The term nontraditional machining refers to a variety of thermal, chemical, electrical and mechanical material removal processes. The impetus for development of nontraditional machining methods has come from the revolution in materials, the demand for new standards of product performance and durability, the complex shapes of products engineered for specific purposes, and consideration of tool wear and economic return. It have also been developed to satisfy the trend toward increased precision and to create improved surface conditions (Walker, 1996). The requirements, and the resulting commercial and technological importance of the nontraditional processes, include:

1. The need to machine recently developed metals and nonmetals. These new materials often have special properties (high strength, high hardness, and high toughness) which make term difficult or impossible to machine by conventional methods.
2. The needs for unusual and/or complex part geometries that cannot easily be accomplished and in some cases are impossible to achieve by conventional machining.

3. The need to avoid surface damage that often accompanies the stresses raised by conventional machining (Groover, 2002).

Many of these requirements are associated with the aerospace and electronics industries, which have grown significantly in recent decades. Nontraditional machining methods are divided into three classifications: Thermal removal – Dissolution and Mechanical abrasion (Illustrated by Figure 1.1).

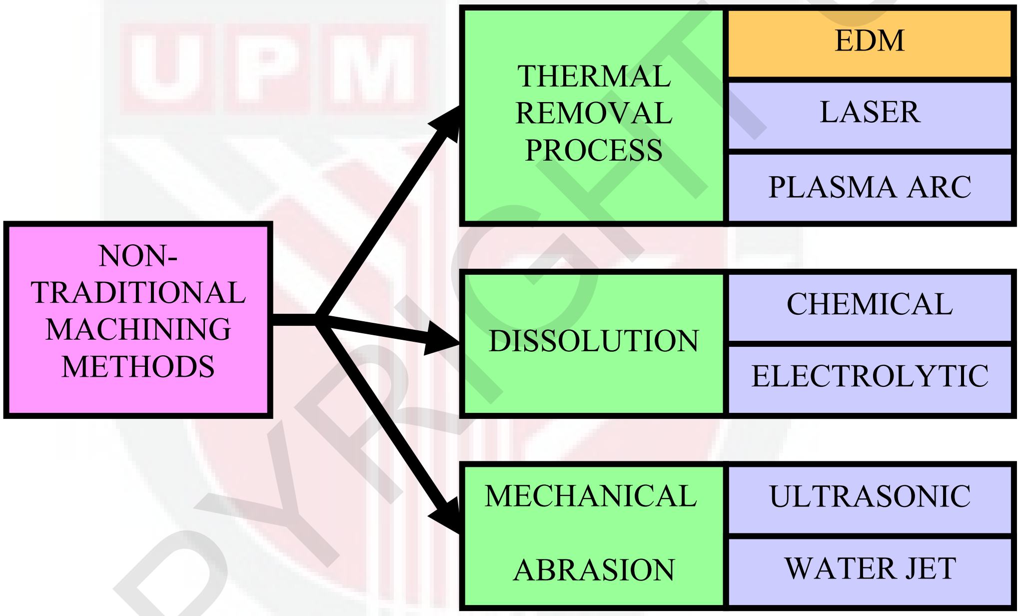

Figure 1.1: Nontraditional Machining Methods (Walker, 1996)

1.1.2 Thermal Removal Process

In thermal removal processes high-intensity heat is focused on a small area of the workpiece, causing it to be melted and vaporized. In all of the thermal removal processes not all of the material removed is vaporized but much of that is melted. Most of the melted material is expelled from the cut by the turbulence of the adjacent vaporization or by the flow of an “assist fluid” used in the process. Some material remains and resolidifies on the surface and cooling rapidly as heat is transferred to the subsurface material. The remaining "recast layer" is likely to have microcracks and residual tensile surface stresses, encouraging those cracks to widen when the material is fatigued. Beneath the recast layer, there is typically a "heat-affected zone" where the material's grain structure may have been altered (see Figure 1.2). One kind of thermal removal process is electrical discharge machining (EDM). In EDM, sparks between the electrode and the workpiece perform the material removal process (Walker, 1996).

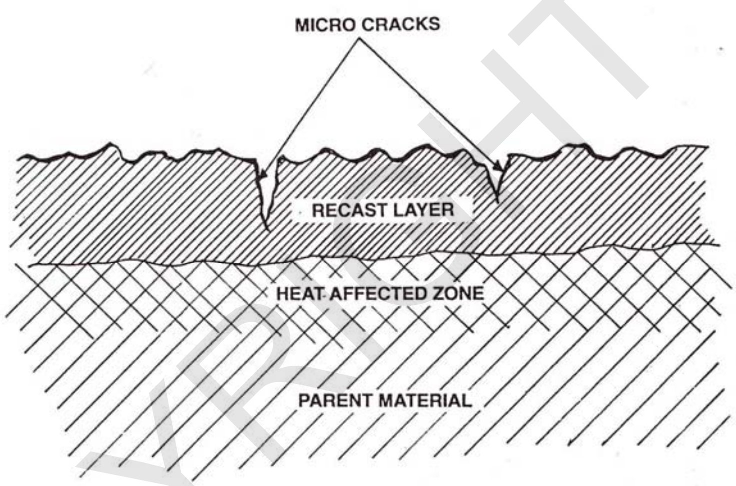

Figure 1.2: Microcracks Appear in the Recast Layer (Walker, 1996)

1.1.3 Electrical Discharge Machining

The principle of electrical discharge machining (EDM), also called electrodischarge or spark-erosion machining, is a non-traditional manufacturing process based on removing material from a part by means of a series of recurring electrical discharges (created by electric pulse generators at short intervals) between a tool called electrode and the workpiece in the presence of a dielectric fluid. This fluid makes it possible to flush eroded particles (mainly in the form of hollow spheres) from the gap, and it is really important to maintain this flushing continuously (Kalpajian and Schmid, 2003).

There were a number of problems faced when mathematical modeling of the EDM process was done. The gap pollution, the hydrodynamic and thermodynamic behavior of the working fluid was hard to model. Getting a model in all with practical technological results was difficult. This inability along with the high demand from the market lead to a more pragmatic and application oriented research into the EDM process.

1.1.4 EDM of Cylindrical Parts

Today's industries especially electrical and aerospace need to produce rotary components, with high precision and high surface hardness, associated with critical application of them. To achieve these requirements, using traditional turning (mechanical material removal) process, to form the workpiece which is hardened in terms to high dimensional precision is not easy and sometimes impossible. Further more, high temperature of mechanical material removal will cause surface structure to be changed; it means workpiece has lost its surface texture (Boothroyd and Knight, 1989). Also a reverse implementation, hardening workpiece next to the machining process will cause failure on dimensional precision as it has been expected (Chanter, 1998). Since, producing small-cylindrical components through the conventional processes, applies a large amount of forces against the workpiece, therefore a probably deformation might be occurred, or sometimes approaching satisfactory dimensional precision will be impossible. Spark-Erosion Machining is one of the convenience methods which can cover mentioned problems in both normal and micro dimensions (Qu, 2002 and Pham et al., 2007).

1.2 Problem Statement

Electrical discharge machining is one of the most useful non-conventional machining methods in industry. As mentioned in section 1.1.3 this process is mostly used in die and mold industry but there are some hybrid machining processes based on EDM such as wire EDM, ultra sonic EDM, powder mixed EDM and so on which individually are kind of processes used for specific applications. As mentioned in section 1.1.4 electrical discharge turning process is a new approach in EDM process for shaping rotary, complex shaped and high-precision products suitable for hard to machine materials (Uhlmann, 2005) suitable for aerospace and engine industry such as servo actuators of helicopter, diesel injector plunger, engine valve, turbo-charger shaft and hydraulic pump actuator. High speed steel (since is a high resistant material) is one of the functional materials for these application and among usual tool materials pure copper is the most suitable electrode for erosion of any kind of steel (ONA H300, 2003). Two quality characteristics namely material removal rate (MRR) and surface roughness (SR) are the most important performance measures for all EDM processes (Qu, 2002). After material properties of tool and work piece these quality characteristics greatly depends on the machining parameters (McGeough, 1988). Usually the desired machining parameters are determined based on experiences or handbook values. However, this does not ensure that the selected machining parameters, results in optimal or near optimal machining performance measures for that particular electrical discharge machine and environment (Lin et al., 2000; Tzeng and Chen, 2007) . Therefore in this study the optimization of electrical discharge turning process includes machining parameters for optimum quality characteristics such as MRR and SR will be carried out in EDM environment of ONA technology. According to literature survey summarized in table 2.1 Taguchi Robust design method is proposed to solve this task.

1.3 Research Objectives

To accomplish this goal in the specific range of parameters of interest, the following objectives will be considered:

1. To consider the significance of Intensity, Pulse durations (on-off), Ionization voltage, Servo and Rotational speed on material removal rate of EDT process and surface roughness of the EDT products.
2. To explore possible way of parameter adjustment to achieve the lowest surface roughness and the highest material removal rate.

1.4 Scope of Study

This study involves optimizing electrical discharge turning parameters and ranges namely: intensity (3 to 5A), pulse-on time (50 to 300 μs), pulse-off time (20 to 180 μs), voltage (80 to 160 V), servo (30 to 60 V) and spindle speed (15 to 40 RPM) in terms to highest MRR and lowest SR. The developed machining setup is innovated for applying on 4-axis EDM machine. Note that for this study surface roughness less